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Toward a Global Governance Framework for Planetary Defense: Legal, Institutional, and Funding Challenges

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Abstract

The Outer Space Treaty (OST) was established to ensure the peaceful use of outer space for the benefit of all humanity. However, it overlooked the existential risks posed by natural celestial threats – such as asteroids and comets – during its formulation. With the increasing recognition of near-Earth objects (NEOs) as credible threats to planetary safety, the need for a globally coordinated response mechanism has become urgent and essential. This paper examines the legal and governance challenges in planetary defense, emphasizing absence of explicit international frameworks to guide deflection missions, assign liability, and govern the use of potentially dual-use technologies like nuclear deflection systems. The paper identifies key legal gaps based on existing treaties, such as the OST, the Liability Convention, and the Rescue Agreement. It proposes the formation of a Planetary Defense Council (PDC) under the auspices of the United Nations. The proposed framework addresses decision-making authority, funding, liability sharing, and ethical considerations, including public communication and global inclusivity. This study frames planetary defense as a collective action problem and underscores the necessity of multilateral cooperation, transparent governance, and equitable participation in protecting life on Earth.

Keywords: planetary defense, space law, international cooperation, Outer Space Treaty

1. Introduction

Planetary defense, protecting Earth from hazardous near-Earth objects (NEOs) such as asteroids and comets, has garnered attention from entities around the globe. Events such as the impact of the Tunguska object in Siberia on June 30, 1908, and the collision of comet Shoemaker-Levy 9 with Jupiter in July 1994 highlight the threat our civilization faces [1]. Another significant impact event is the Chicxulub crater by an asteroid of 9 km diameter and widely believed to be the primary cause of Cretaceous-Paleogene (K–Pg) mass extinction [2]. One significant Potentially Hazardous Asteroid (PHA) is the asteroid (99942) Apophis, discovered in 2004 by Tucker, Tholen, and Bernardi at the Kitt Peak National Observatory in Arizona [3]. Initially, the chances of Apophis impacting Earth in 2029 were posed at 2%, though further observations have reduced this probability. Apophis will pass within a distance closer than the orbit of geostationary satellites during its close approach on April 13, 2029 [3]. The probability of an asteroid impacting Earth and causing a civilization-ending impact may be low, but the consequences would be catastrophic.

National and regional space agencies, such as NASA's Planetary Defense Coordination Office and the European Space Agency's (ESA) Space Safety Program, actively detect and track NEOs. While

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technological advancements have equipped us better, the global nature of the threat demands a more cohesive and inclusive framework, such as expanding the role of international organizations (UN Office for Outer Space Affairs - UNOOSA) and leveraging existing mechanisms like the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG). The involvement of the private sector requires appropriate regulatory oversight to develop technological solutions of global interest. Early detection and precise tracking of NEOs are crucial for effective planetary defense [4]. The Double Asteroid Redirection Test (DART) mission, in 2022, altered an asteroid's trajectory [4]. Despite detection and mitigation technology advancements, a key challenge remains: a unified global governance framework to coordinate these efforts and address legal uncertainties.

Several international laws and treaties have been formed in the past that govern space-related activities, such as the Outer Space Treaty (OST) [5], Liability Convention (LC) [6], Rescue Agreement (RA) [7], and others. Despite these existing frameworks, there are no explicit laws for planetary defense activities. While the Outer Space Treaty prohibits placing nuclear weapons in space, it lacks guidelines on placing kinetic impactors or nuclear explosive devices (NEDs) in space for planetary defense efforts/activities. Similarly, existing treaties lack guidelines on resource allocation, data sharing, and financial commitments by the participating nations.

This paper examines potential planetary defense scenarios, explores responsibility, liability, and decision-making authority issues, and proposes a solution to unify planetary defense efforts and governance challenges.

2. Planetary Defense and Threat Scenarios

The concepts, technology, and systems necessary for detection and collision prevention are collectively termed "planetary defense" [8]. Planetary defense requires global cooperation but faces significant collective action challenges. As Iwry [9] summarizes –

- P-2.1 the **free rider problem**, in which parties underinvest in a non-excludable common good while benefitting from other parties' contributions.
- P-2.2 the **tragedy of the commons**, in which parties collectively overuse or deplete a shared resource due to a lack of regulation or incentives for conservation.
- P-2.3 the **prisoner's dilemma**, in which parties refuse to cooperate due to mutual fear of betrayal, resulting in suboptimal gains for all parties.

These challenges are obstacles to establishing a unified global planetary defense strategy.

Most known asteroids reside in the asteroid belt between Mars and Jupiter. External disturbances – gravitational interactions and non-gravitational forces like the Yarkovsky effect – constantly alter their trajectories. Not all asteroids are a threat; those larger than 140 meters in diameter and in proximity to Earth's orbit within 0.05 astronomical units (AU) are classified as PHAs. Asteroids with a diameter of 140 meters or more can cause regional devastation. Ground-based and space-based observations for accurate orbit determination and collision risk assessment closely monitor these PHAs. The following subsections present some plausible threat scenarios.

2.1. Asteroid Impacting Earth

A confirmed PHA impact scenario represents the most urgent planetary defense challenge. If well-defined policies and strategies are not in place for a coordinated defense action, delays and public unrest could lead to chaos. The key concerns would be:

- Q-2.1 Who conducts the risk assessment? If it is a joint multinational effort, do all the participating entities concur on the methodology and outcome of the assessment?
- Q-2.2 Is there a resource allocation/distribution plan, such as the responsibility of the complete mission, facilities, staff/engineers, locations, and timelines?
- Q-2.3 Given a late detection and a short lead time to impact, how is risk and impact assessment handled?
- Q-2.4 Public perception is crucial for planetary defense but cannot halt decisions over prolonged public debate. How is democratic input balanced with expert-driven choices and actions?
- Q-2.5 In impact regions, should decision-making authority rest primarily with government agencies, or should local communities and affected populations have a significant role?

2.2. Asteroid Collision with Space Object

Asteroid collision with a space object will increase space debris and unintended directional projectiles. These fragments could enter the Earth's atmosphere. In addition, if the asteroid fragments do not burn up in Earth's atmosphere during entry, they pose an additional threat to life on Earth. Besides, the collision of an asteroid with any other satellite or constellation would affect global communication, GPS, weather monitoring, military surveillance, commercial operations, banking transactions, and foreign trade. Space debris could disrupt planetary defense spacecraft and leave the Low Earth Orbit (LEO) unusable for future generations. Some critical questions to answer are:

- Q-2.6 Do we have advanced systems that can send a warning signal in real-time for incoming debris and inform airlines to prevent potential collision with a flight?
- Q-2.7 What are the protocols if a non-impacting nation operates the system?
- Q-2.8 Who is responsible for such a system, network, and communication protocol?
- Q-2.9 What are the protocols for an asteroid impact emergency warning?

2.3. Kessler Syndrome

An uncontrollable chain reaction of satellite collisions could initiate if an asteroid impact triggers Kessler Syndrome. The exponentially increasing space debris poses severe risks to LEO operations, potentially making it unusable for decades. The consequences could include:

- Loss of global communication networks (internet, satellite phones).
- Disruptions to military surveillance and early warning systems.
- Impacts on GPS-dependent services (aviation, shipping, financial transactions).
- Increased risk for future crewed space missions due to hazardous debris.

Given these risks, it is crucial to establish emergency protocols for mitigating Kessler Syndrome events. Pertaining questions seeking answers would then be:

- Q-2.10 Are the non-participating nations accepting the risk of their communication system shutdown?
- Q-2.11 Is there an emergency plan and protocol for Kessler Syndrome trigger?

3. Responsibility, Liability, and Decision-making Authority

Responsibility is the distribution of duties among entities or States involved in planetary defense. This distribution may be equal or proportional and can be established voluntarily or by agreement. The main aspects of responsibility are execution, communication, and evaluation.

Liability refers to legal accountability for consequences resulting from actions or failures. Space law usually involves monetary compensation. However, monetary remedies alone may not constitute adequate or equitable justice in planetary defense, where lives and ecosystems are at stake.

Several articles of the OST are relevant, yet insufficiently clear, in the context of planetary defense missions. We discuss OST, LC, and RA articles as follows:

- T-3.1 Article II of the OST prohibits the national appropriation of outer space, including the Moon and other celestial bodies, by claim of sovereignty, use, occupation, or other means. While this principle was intended to prevent territorial competition in space, it also creates ambiguity in planetary defense, where intervention might involve altering an asteroid's composition.
- T-3.2 Article IV of the OST prohibits any nation or organization from placing weapons near the Earth, Moon, celestial body, or even in space [5, 10]. However, it grants permission to use military personnel, equipment, or facilities for scientific exploration or peaceful uses of outer space. Since planetary defense has not been explicitly included in the exploration or peaceful use category, it leaves a gap in the use of outer space for planetary defense activities that may involve deploying mass destruction technology, such as a kinetic impactor or nuclear explosion device (NED) in space. This distinction is critical. While the OST permits using military assets for peaceful purposes, it does not clarify whether technologies such as nuclear devices for asteroid deflection fall under that umbrella. This lack of specificity could inhibit timely mitigation efforts in a real-world crisis.

T-3.3 Article VII of the OST states that the State party from whose territory or facility an object to outer space is launched is internationally liable for damage to another State party [5]. While this is an efficient approach to ensuring the safety of life on Earth alongside technological advancements, it may cause State parties to be not fully committed and/or hesitant to participate in planetary defense activity.

T-3.4 Article II of the LC identifies the launching State as liable to pay compensation for damage caused by its space object on the surface of the Earth or to aircraft in flight [6]. This principle was invoked in the Kosmos 954 incident, where the Soviet Union compensated Canada after a nuclear-powered satellite re-entered and dispersed radioactive debris over Canadian territory [11].

T-3.5 Article V of the RA establishes launching authority as the bearer of the expenses for recovering space objects found outside their jurisdiction or territory [7]. Since it applies to astronauts only, a gap in economic burden restricts planetary defense activities.

T-3.6 Article IX of the OST defines a provision where if a State party believes that its planned operation in outer space could cause potentially harmful interference with other State parties, then they could proceed after international consultation [5]; however, this is true in the context of exploration. Again, planetary defense has not been explicitly mentioned. Therefore, it leaves the applicability of this article open to interpretation.

T-3.7 Risk pool, a form of risk management, is assembled to protect insurance companies against catastrophic risks. The concept could be used as a collective liability mechanism to manage and compensate for damages from mitigation efforts.

The use of outer space for planetary defense activities is incomplete due to non-explicit guidelines, and the economic aspect compounds these obstacles. Not all nations consider investing in planetary defense a reasonable effort, especially if they are not at risk. Even if some nations consider participating, they may be restricted or limited, given their economic priority.

4. Proposed Solution

4.1. Planetary Defense Council

Since planetary defense is a global concern and requires global participation, there must be a dedicated intergovernmental body, possibly under the UNOOSA, similar to the International Atomic Energy Agency (IAEA) or Intergovernmental Panel on Climate Change (IPCC). The primary functions of this intergovernmental body would be to:

F-1: authorize deflection missions

F-2: facilitate technology transfer among States and establish technical standards

F-3: coordinate NEO monitoring efforts through multinational space agencies

F-4: define risk thresholds and response protocols

F-5: provide a forum for dispute resolution

For effective functionality, the following implementation ideas must be incorporated:

S-1: Regardless of nationality, every State must have the right to vote and to nominate their representative.

S-2: While a rotating chairmanship typically helps, since these are multiple years of effort, the objective must be to minimize the chaos and policy changes.

S-3: The Council must have the right to override national decisions in critical impact and/or short lead-time scenarios.

S-4: The Council must inherit an operational strategy for balancing global coordination with national sovereignty from the International Civil Aviation Organization (ICAO).

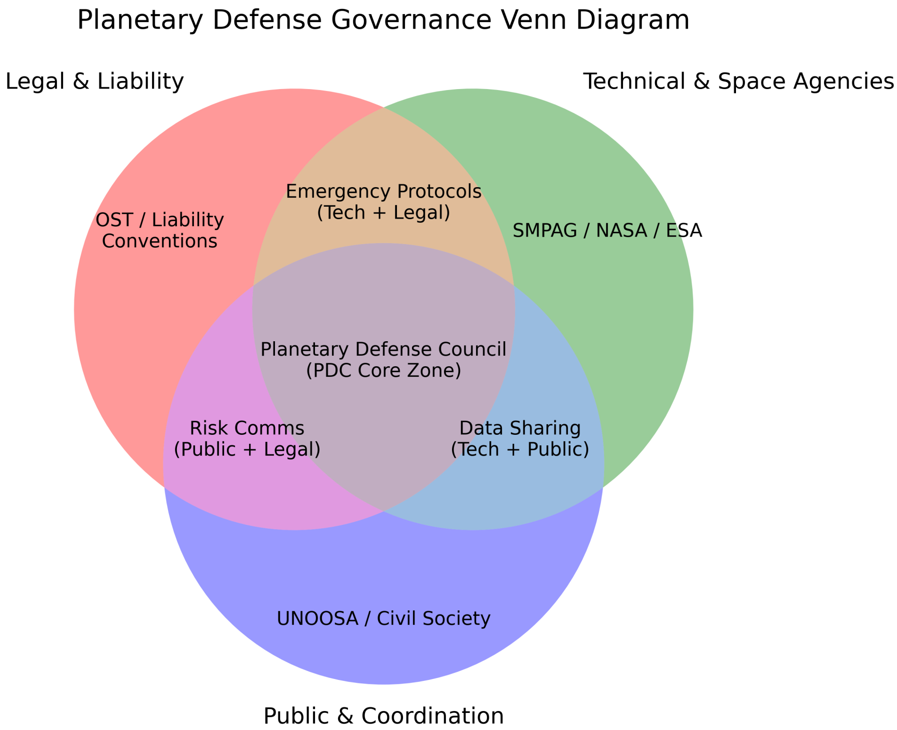

Figure 1: Venn diagram for Planetary Defense Governance showing overlapping regions of framework facets.

Amidst geopolitical rivalries, creating a UN-affiliated body requires the approval of the General Assembly, budgeting, negotiation, and a multi-year diplomatic effort; this might derail or delay consensus.

The Venn Diagram in Fig. 1 illustrates the intersection of three primary governance domains critical to planetary defense: legal & liability frameworks, technical and space agency capabilities, and public & international coordination. The intersecting zones of legal and technical domains address situations of emergency protocols where deflection actions must be authorized within legal constraints. The overlapping of legal and public domains ensures public engagement, transparency, and the right to be informed. A cross-over of technical and public domains allows data-sharing and public consultation. The central overlap establishes PDC as the intergovernmental body integrating legal authority, technical capability, and global inclusivity to coordinate planetary defense missions.

4.2. Planetary Defense Liability Protocol

A new annex or protocol to the Liability Convention must be explicitly created for planetary defense missions. The nations involved in asteroid threat mitigation must be exempted from liability as "Good-faith mitigation immunity" if damage occurs as part of an internationally approved deflection attempt. For fair treatment, a shared-risk clause must force all contributing nations to assume proportional liability based on participation. Accordingly, the new annex must provide the following core mechanisms to enforce immunity, liability sharing, and dispute settlement:

- S-5: The annex must establish a dispute resolution body.
- S-6: The Council must approve each planetary defense mission for good-faith mitigation immunity, drawing on parallels from the Vienna Convention on Civil Liability for Nuclear Damage [12].
- S-7: Liability sharing must be determined proportionally based on investment, risk exposure, and technological involvement.

4.3. Global Planetary Defense Fund

Establishing a global fund for planetary defense would smooth many knots over the financial liability and burden. This fund must be used for all planetary defense R&D, planetary defense missions, and

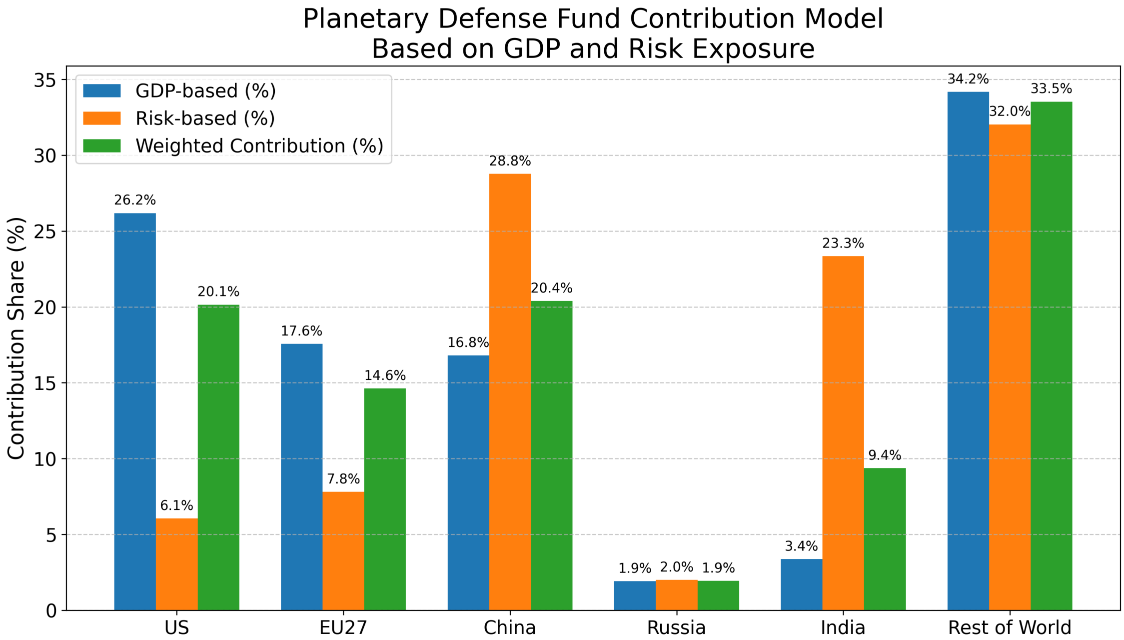

Figure 2: Comparison of GDP-based [13], risk-based, and hybrid funding contributions to a proposed Global Planetary Defense Fund. The hybrid model uses a weighted average (70% GDP and 30% risk exposure), where risk is calculated using a composite of national population and urban density. This approach ensures that economic capacity and vulnerability to asteroid impact inform funding responsibilities.

compensation to affected parties if unintended damage occurs from the mitigation efforts; this raises an important question about who contributes how much. A simplified version could be contributions weighted by the participating nations' Gross Domestic Product (GDP), population, and urban density. Additionally, based on the space activity index, spacefaring nations could contribute more, as they are technology-ready and are likely to be active participants. Further, commercial space companies should contribute separately from the State. To propose a fair and strategic allocation of funding responsibility among nations for planetary defense, we introduce a hybrid model that combines:

- **Economic Capacity:** represented by each country's global nominal GDP.
- **Risk Exposure:** a composite of population and urban density, indicating potential impact severity.

Figure 2 shows the composite and weighted contribution based on GDP and risk exposure. The risk exposure of China is highest due to its extensive land area; however, this risk exposure does not account for the trajectory and impact site of any particular asteroid. This global fund must be managed with transparency and administered by the PDC.

4.4. Technology Exchange Protocol

Due to the sensitivity of space technology, lack of mutual trust, and fear of misuse, nations may not be wholly inclined and transparent in sharing technological advancements for planetary defense efforts. Establishing an international planetary defense technology exchange act/protocol shall make clear the boundaries between planetary defense and military technology. The information on such technological advancements is sensitive, and there must be secure channels, like an intranet, under the Council to prevent misuse. The technology must be categorized by sensitivity, such as civilian use, dual use with oversight, or restricted for Council clearance. Besides, an established compliance framework must incorporate inspections, red-flagging mechanisms, and repercussions for misuse. An example of dual-use technology sharing under strict terms is the Nuclear Non-Proliferation Treaty (NPT) [14]. Similar to Article V of the NPT, which permits nuclear explosions for potential benefits from any peaceful application under international observation, a provision could be extended for using nuclear explosions for asteroid threat mitigation.

4.5. Space Neutrality Agreement

The OST must be updated or extended to establish rules for the temporary and only defensive use of nuclear technology for asteroid deflection and ban the retaliatory misuse of planetary defense technologies. A practical methodology for defensive use compliance includes verification protocols such as regular and periodic reporting and surprise inspections. States must have the right to voluntarily adopt the agreement as a supplemental treaty to the OST. The Wassenaar Agreement [15] should be considered for export controls for conventional arms and dual-use goods.

4.6. Inheritance and Extensions from Laws Beyond Space

Laws in space are separate, but in principle, they resemble laws from other domains. For instance, Maritime Laws can be extended to planetary defense. To see how these well-established maritime principles can guide the development of space law for asteroid mitigation, we can identify three key areas of adaptation and institutional design:

- I-1: **Adapting Maritime Principles to Space Law [16]**: The Law of Salvage rewards those who aid vessels in distress and encourages entities actively participating in NEO detection and deflection efforts. This principle would expedite early intervention and guarantee that such efforts are acknowledged and compensated to encourage more stakeholders to participate in planetary defense actions. Space law could be interpreted as procedures that permit emergency asteroid mitigation actions to proceed without the customary procedural requirements when time is of the essence. Similarly, the maritime concept of a Port of Refuge requires ports to accept distressed ships to prevent more significant harm.
- I-2: The International Maritime Organization (IMO) is an example of a specialized governance body with a comprehensive regulatory framework for shipping that considers safety, environment, and legal issues. Instead of combining national approaches, the model brings together 176 member states [17] to adopt regulations. A similarly specialized organization might standardize procedures and encourage global collaboration in planetary defense scenarios.
- I-3: **Proposed Framework for Enhanced Cooperation**: A Planetary Defense Coordination Agreement (PDCA) is suggested to implement these ideas. Similar to the standardized processes in the International Regulations for Preventing Collisions at Sea (COLREGs), the agreement would specify reliable protocols for decision-making. The PDCA would assist in creating comprehensive guidelines for evaluating NEO threats, selecting mitigation strategies, and guaranteeing activity transparency within participating States. This agreement would address one of the main challenges to involvement in asteroid mitigation efforts by introducing liability exemptions for actions taken in good faith during emergency deflection attempts. The PDCA would also establish an equitable system for allocating the expenses of planetary defense projects according to each nation's GDP and technological capability. The purpose is to prevent the financial burden from falling unfairly between a few States.

As a way to visualize where existing treaties fall short—and how the proposed PDC fills those gaps—the coverage matrix in Fig. 3 maps each key parameter against the Liability Convention, OST, Rescue Agreement, and our new Protocol.

Creating an organization similar to IMO should be a key framework component. The group seeks to facilitate the fair distribution of resources and technology, supervise the implementation of PDCA, and organize global monitoring activities. To make sure the technical standards for detection and deflection are functional and universally applicable across various national systems, the organization will develop them. Additionally, by removing surveillance gaps and system redundancies, the organization will spearhead the monitoring efforts to keep a thorough eye on NEOs that might be threats. Finally, the organization encourages technology transfer between nations to push the capability of global response to asteroid threats. Therefore, all States could participate in detection and deflection efforts regardless of their current capabilities.

5. Conclusion

As the global threat posed by near-Earth objects (NEOs) continues to evolve, the urgency of a coordinated international response becomes increasingly evident. While technological advances such as the DART mission demonstrate our growing capability to detect and deflect hazardous asteroids, the

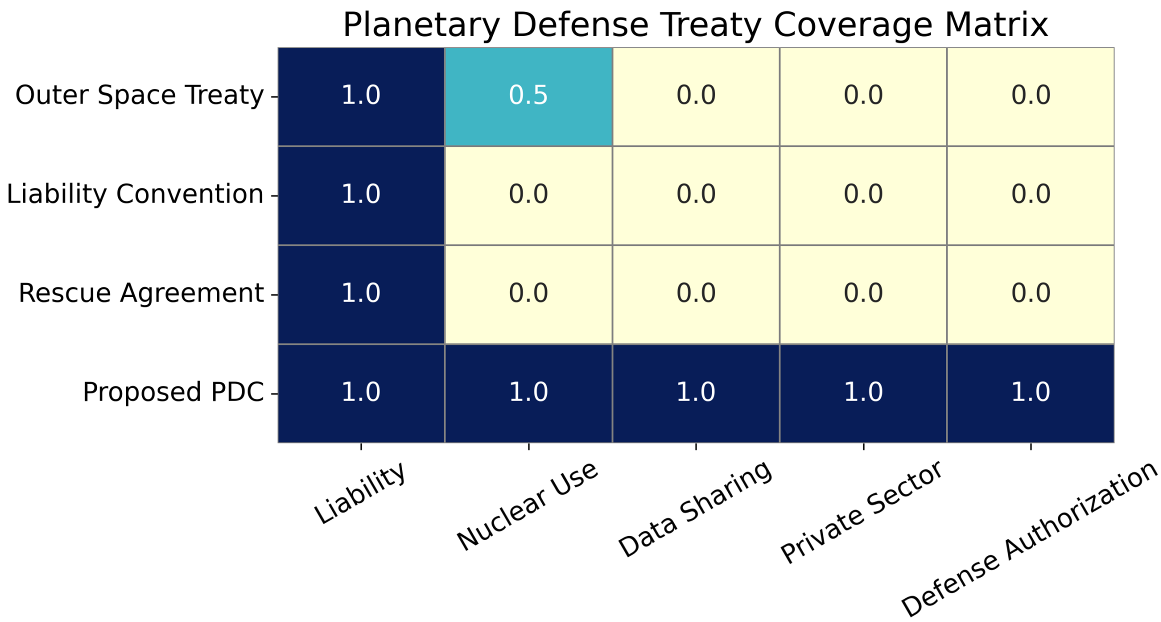

Figure 3: The coverage of key parameters by individual treaties and proposed PDC shown in matrix form.

absence of a robust global governance framework creates legal uncertainty, inhibits cooperation, and delays timely action.

This paper identifies key shortcomings in existing treaties, including the Outer Space Treaty and the Liability Convention. It proposes a multifaceted solution: creating a Planetary Defense Council, a revised liability protocol, a global fund, a structured technology exchange protocol, and an updated space neutrality agreement. We offer a feasible roadmap for integrating space law, policy, and collective action theory based on analogies from maritime law and international institutions such as the IMO and IAEA.

Future work should focus on operationalizing the proposed Planetary Defense Council, modeling cost-sharing and contribution frameworks, and exploring public engagement strategies. Special attention must also be given to integrating private space actors and ethical frameworks for decision-making in high-stakes deflection scenarios. Defending Earth from asteroid threats is a technological challenge and a test of our ability to act as a unified global civilization. It is time to move beyond ad hoc responses and build a cooperative legal foundation for planetary safety.

Appendix A. Hybrid Contribution Model for Global Planetary Defense Fund

Model Overview: The final contribution share for each region is computed as:

$$C_i = w \cdot \left(\frac{G_i}{\sum G}\right) + (1 - w) \cdot \left(\frac{R_i}{\sum R}\right)$$

where:

- C_i is the contribution share of country or region i.
- G_i is the nominal GDP of i.
- $R_i = P_i \cdot D_i$ is the risk exposure, calculated from population (P_i) and a normalized urban density factor (D_i).
- w is the weighting coefficient (we use $w = 0.7$ to prioritize GDP).

This model balances ability-to-pay with impact vulnerability. For instance, China and India have higher contributions under the risk model due to their large populations and urban areas, while the US maintains a leading share due to its economic weight. The inclusion of risk exposure helps ensure that nations not traditionally seen as spacefaring still have a voice and a stake in planetary protection.

Table A.1: Input data used for calculating hybrid funding shares [13]. Urban density is normalized on a scale from 0 to 1.

Region	GDP (T USD)	Population (B)	Urban Density Index
US	27.72	0.33	0.90
EU27	18.59	0.45	0.85
China	17.79	1.41	1.00
Russia	2.02	0.14	0.70
India	3.57	1.43	0.80
Rest of World	36.18	3.14	0.50

Table A.2: Calculated Shares: Hybrid funding contributions based on a 70% GDP and 30% risk exposure weighting.

Region	GDP Share (%)	Risk Share (%)	Final Contribution (%)
US	22.0	11.1	18.6
EU27	15.8	9.8	13.4
China	15.8	28.0	20.7
India	3.2	23.5	10.3
Russia	1.9	2.8	2.2
Rest of World	35.3	24.8	34.8

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